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# STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

## FINAL REPORT

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## APPENDIX C
## RECOVERY AND REUSE 120-IN.-DIAMETER SOLID ROCKET MOTOR BOOSTERS

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# STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

## FINAL REPORT

APPENDIX C
RECOVERY AND REUSE
120-IN.-DIAMETER
SOLID ROCKET MOTOR BOOSTERS

15 March 1972

Prepared Under
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for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA

by

**United Technology Center**

DIVISION OF UNITED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

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## PREFACE

The results of previous studies on the recovery of SRMs have indicated that the most expensive elements of the SRM hardware (i.e., case segments, forward and aft closures, attach structures, and nozzle steel) are recoverable with an attrition rate of less than 20%, and that these high recovery rates are primarily due to four factors:

A. Utilization of a proven parachute recovery technique

B. Low impact loads resulting from SRM entry into water at velocities under 90 ft/sec

C. Inherent strength and stiffness of the SRM, which is designed not only for external flight loads but also for high internal pressures on the order of 900 to 1,000 psi

D. Segmentation and interchangeability of all SRM hardware components.

Recovery system operations are described briefly in the following paragraphs.

The launch vehicle rises through the atmosphere and accelerates until SRM burnout. After booster burnout, the SRM separates from the orbiter and begins tumbling at decreasing rates until free of the atmosphere. The energy at burnout sustains the SRM in ballistic flight to an apogee at 31 nm. During this period "in vacuo," the tumbling rate is constant at about 10 rpm. As the SRM enters the sensible portion of the atmosphere, the nozzle end tends to lead the forebody, and the SRM nutates. At this point, temperatures have peaked to $400^{\circ}$ to $500^{\circ}$F by aeroheating. At 32,000 ft, the ribbon drogue is deployed, and 43 sec later the vehicle is positioned vertically, nozzle down, with four 100-ft-diameter canopies mushrooming 200 ft overhead. Eight thousand feet below and several miles away, recovery ships maneuver toward the impact points.

The heat shield crushes under water impact loads at an entry speed of 43 mph (63 ft/sec). Within 5 ft of water entry, the major impact forces are dissipated. The slap-down effect, as the SRM nose drops, is absorbed by the high strength and stiffness of the steel case; however, the relatively thin aluminum nose cone could be damaged by secondary impact in high seas. The SRM experiences the normal inertia and buoyancy forces during the remainder of the penetration. A maximum immersion of 40 ft results after impact. The motion of the SRM is thus highly damped, and the SRM shortly comes to rest intact on the sea with the nozzle immersed slightly below the waterline and with a large volume of air entrapped within the steel motor case to ensure flotation.

Location aids enable the recovery ships to engage the floating SRMs. Pyrotechnic and explosive circuits are disconnected from the SRMs, and inflatable rubber rings are then installed fore and aft to provide flotation stability and protection from damage as the SRMs are floated into an LSD. Four SRMs are retrieved within 6 hr after touchdown, and the components are off-loaded at the ETR naval docks 26 hr after impact. Each item is then cleaned and evaluated for refurbishment, reprocessing, and reuse.

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ILLUSTRATIONS



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## ABBREVIATIONS

| | |
|---|---|
| ETR | Eastern Test Range |
| ISDS | inadvertent separation detection system |
| LSD | landing ship dock |
| MEOP | maximum expected operating pressure |
| MPI | magnetic particle inspection |
| MRB | material review board |
| NDT | nondestructive testing |
| SMAB | solid motor assembly building |
| SRM | solid rocket motor |
| TVC | thrust vector control |
| UTC | United Technology Center |

## 1.0 INTRODUCTION AND SUMMARY

### 1.1 INTRODUCTION

This study provides the baseline for a space shuttle configuration utilizing four parallel-burn, 120-in.-diameter SRMs with seven segments and TECHROLL® seal movable nozzles. The concept and general economic benefits of SRM recovery presented herein are equally valid for the series-burn SRMs or the 156-in.-diameter SRMs, provided that those SRMs are also designed for the same strength, stiffness, segmentation, and interchangeability as the 120-in. design, and that those SRMs are also recovered as individual units.

In late 1963 and again in 1965, feasibility studies were initiated by UTC to investigate SRM recoverability. These studies were based upon recovery of the SRM boosters for the Titan III-C. Ground rules established at the outset of the study precluded SRM modification that required significant changes in motor qualification or schedule under the Air Force 624A Program. Even with this restriction, the study determined that the recoverable booster concept was completely feasible, both technically and economically.

The present study has not only substantiated the gross results of the 1963 and 1965 studies but has confirmed the favorable economics of the parachute recovery system. Parachute recovery has been selected as the best method, principally because it can accomplish the task with a minimum development cost and time to achieve operational recovery status ..is system affords the highest probability for achieving the large cost reductions presented in section 2.0.

The study accomplished the following objectives: (1) formalized booster recovery requirements; (2) described technical properties of the applicable recovery system; and (3) examined SRM design compatibility considerations including separation, atmosphere reentry, stabilization, terminal deceleration, water impact, immersion, flotation, retrieval, refurbishment, and reuse.

Although the basic purpose of recovering space boosters is to reduce the overall cost of a space booster system, certain other benefits may accrue.

One is the upgrading in reliability afforded by first-hand evaluation of flight hardware upon recovery. Another is a demonstration of the feasibility of reusing booster vehicles. UTC feels that this will become an economic necessity in the near future. With a recoverable system, the direct operating costs can be reduced significantly.

## 1.2 RESULTS AND CONCLUSIONS

Specific results and conclusions reached in the course of the study are:

A. From the standpoint of minimum cost and development, parachutes are the best means of achieving SRM recovery.

B. A cost saving of approximately \$800 million for mission model No. 1 (445 shuttle flights) can be realized by recovering major components of the SRM.

C. The 120-in.-diameter SRM inert weight of 82,000 lb results in an impact velocity of 63 ft/sec with four 100-ft parachutes.

D. Major SRM components can be reused safely. The margin of safety is sufficient after seven reuses to ensure man ratings.

E. Hydrotests are required to qualify motor cases for reuse.

F. From the standpoint of hydrostatic loading, nozzle-first vertical water entry is more favorable than nose-first entry.

G. More than 65% of the inert initial dollar value can be expected to be recovered from nozzle-first water impact at 63 ft/sec.

H. The SRM tumbles after separation at a fairly slow rate, and after reentry stabilizes to the nozzle-first attitude with slow decaying roll and nutation about the center of gravity.

I. The weight added to provide a parachute recovery system is 3,500 lb per SRM; the effect of booster recovery system weight on the shuttle payload is, therefore, slight.

J. Aerodynamic heating will not be excessive during reentry; it is not expected to exceed 550$^{\circ}$F on critical areas.

K. Temperature of the nozzle throat insulation will be 2,500°F at water impact; the insulation will be completely destroyed by immersion.

L. Broadside entry results in damage to the SRM. However, vertical nozzle-first impact at 63 ft/sec will not cause structural damage to the major components. Buckling depths are not exceeded. Nozzle-first entry results in loss of the nozzle extension cone. The slap-down effect as the SRM nose drops is absorbed by the high strength and stiffness of the steel case; however, the relatively thin aluminum nose cone could be damaged by secondary impact in high seas.

M. No design changes are required in the SRM to affect recoverability except for incorporation of the parachute system in the nose cone and the addition of one hydraulic shock absorber to supplement the existing TVC hydraulic actuators, which in themselves are excellent shock absorbers. The aft portion of the nozzle exit cone is also an excellent design since it is fabricated of wrapped silica-phenolic cloth which will fail incrementally, thus absorbing and dampening the impact loads.

N. The SRM will float unaided with the nozzle immersed at a pitch attitude of 3 to 6 degrees. Survivability is excellent in all but the most stormy seas.

O. SRMs will be in the water less than 20 hr before reaching ETR by LSD. The LSD can easily load four SRMs, wash them down with fresh water, and return to the ETR naval docks for off-loading within 10 hr.

P. Salt water and galvanic action will not pose recovery problems to the major recoverable components providing a rinse and dry procedure is initiated after water removal. Experience with refurbishment of hardware for the five-segment 120-in.-diameter SRM from the Titan III Program indicates that water effects, corrosion, and hydrogen embrittlement experienced over a 4-year period did not affect refurbishment and successful test of such hardware on the seven-segment 120-in.-diameter SRM qualification program. To preclude salt water penetration into crevices of the nose section and aft skirt components, a rubberized spray coating will be used after component assembly.

Q. The impact analysis shows a maximum of 5.8-g impact load for SRM splashdown at 63 ft/sec. (The motor itself is designed for a sustained axial load of 10 g under fully loaded conditions and is, therefore, capable of withstanding axial decelerations greater than 16.5 g. On this basis alone, SRM water impact velocities in excess of 90 ft/sec can be tolerated.) However, an additional factor of safety is achieved by using the aft end hydraulic nozzle actuators as shock absorbers. The load mitigation from these hydraulic shock absorbers is not included in the analysis, but will significantly reduce the impact of gravitational acceleration on the SRM.

## 1.3 RECOMMENDATIONS

It is recommended that a recovery system development program be initiated. Full-scale demonstrations should include:

A. Water impact test of the motor at 63 ft/sec to verify SRM component survivability using existing motor hardware

B. SRM water flotation tests to verify and evaluate the flotation attitude, stability, leakage characteristics, pickup requirements, and effects of surface wave action

C. Tests to verify that shock loads resulting from entry into the water at 63 ft/sec do not ignite the safe and arm pyrotechnics for the destruct and thrust termination system

D. Tests to evaluate the effect of salt water, salt-water spray, and corrosion on SRM components

E. Evaluation of protective coatings for SRM hardware

F. Air-drop tests of the parachute recovery system using dummy payloads (or 1200-series motors)

G. Multiple hydrotesting of three segments and two closures to establish multiple reuse reliability using existing seven-segment test hardware

H. Motion picture coverage of the next Titan III launch to evaluate SRM postseparation dynamics

I. Nozzle impact load testing to verify action of the shock absorbers and failure mode of the extension cone

J. Evaluation of LSD recovery operations at sea.

## 1.4 DISCUSSION

The following paragraphs discuss the proposed plan for recovery, retrieval, and reuse of the SRMs.

### 1.4.1 Parachute System Sequence

The parachute system consists of the following components which are similar to those qualified from previous programs:

| Component | Program |
|---|---|
| Pilot chute extraction system | Gemini |
| Pilot chute | Project Asset |
| Mortar | Gemini and Mercury |
| Drogue chute | Project Asset |
| Main parachutes (modified) | Classified Air Force Program |
| Sequence controller | Apollo |

The sequence controller is activated at SRM burnout by the same signal which activates SRM separation (see figure 1-1). At an altitude of 32,000 ft, the nose cone is separated and, following a 2-sec delay, the pilot chute is deployed by mortar ejection. The pilot chute extracts the 44-ft-diameter drogue chute, which is fully disreefed at an altitude of approximately 19,000 ft.

At an altitude of 10,000 ft, the sequence controller initiates drogue release (see figure 1-2). The drogue assembly then extracts the four 100-ft main parachutes. At 8,000 ft, the main chutes are disreefed, providing a terminal descent velocity of approximately 63 ft/sec.

Two seconds after water impact, the main chutes are separated from the booster on the command of an impact switch signal, which also activates flashing lights.

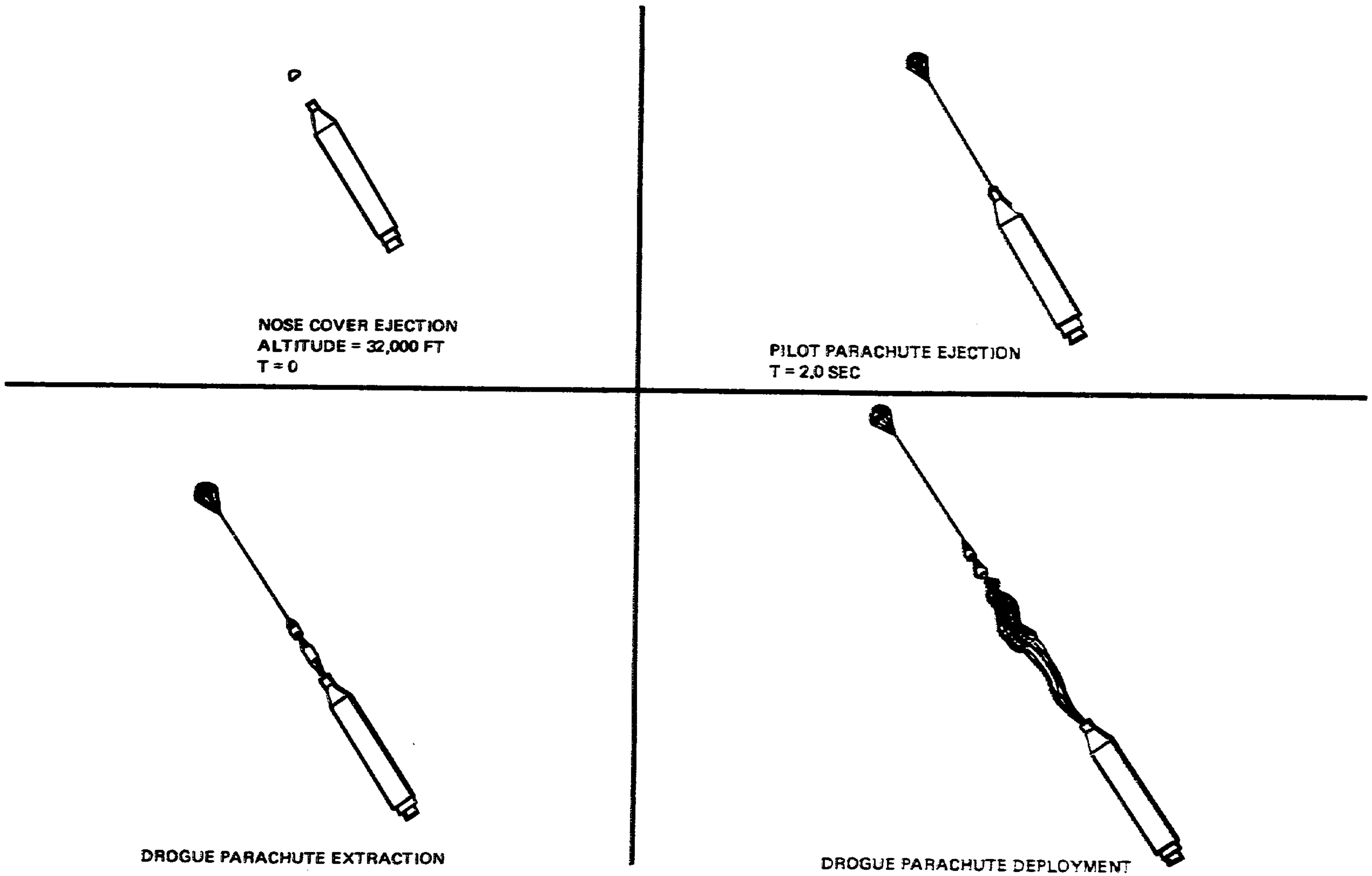


Figure 1-1. Parachute System Sequence

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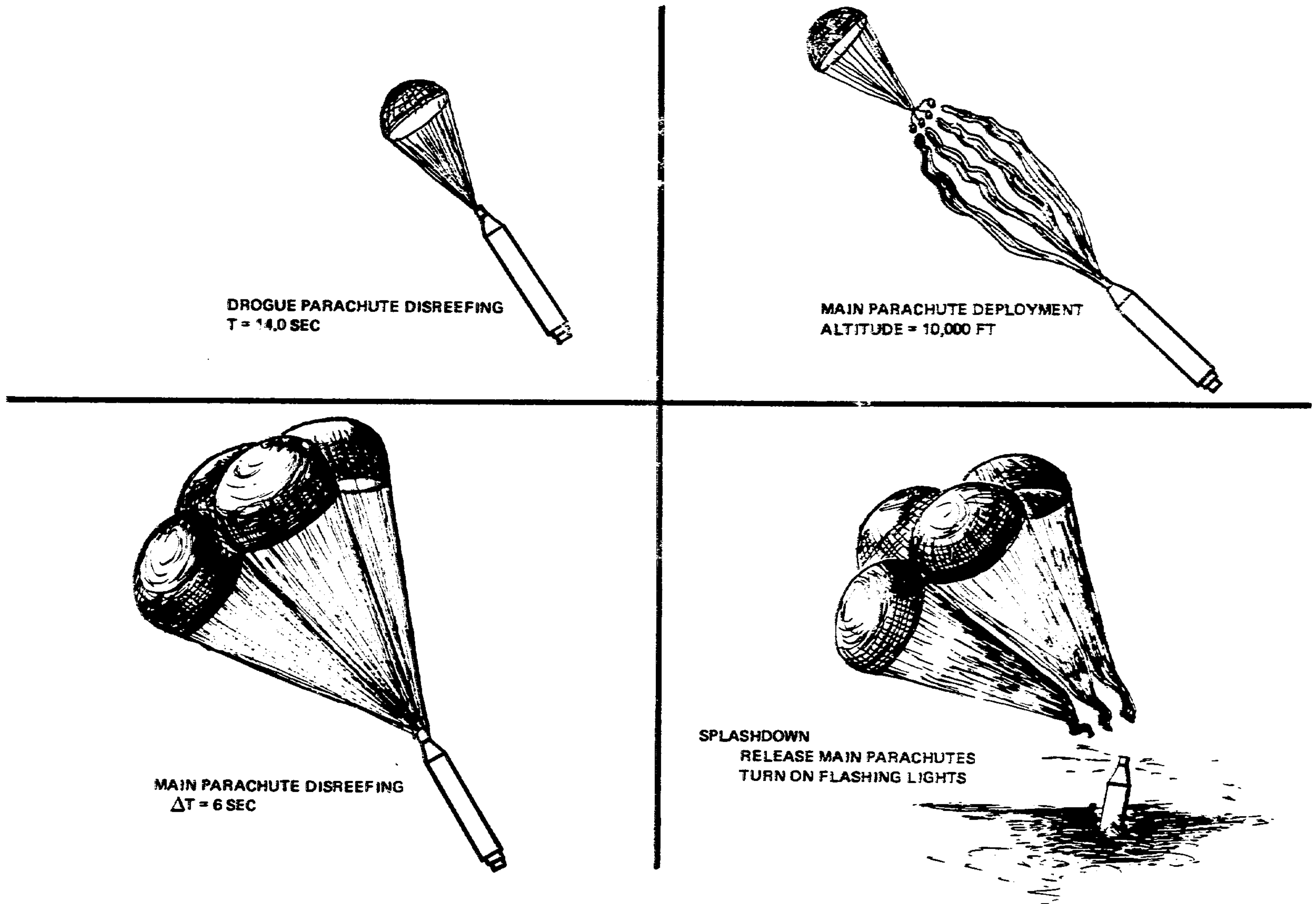


Figure 1-2. Parachute System Sequence

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### 1.4.2 Parachute Sequence Controller

The sequence controller subsystem, which consists of an electric sequencer, transducers, and an electrical harness, provides the necessary sequence of events during deployment and recovery cycles. Design studies have indicated that the basic Apollo command module sequencer can be used, but with the abort sequence eliminated. This sequencer contains two parallel systems and has a reliability factor in excess of .9994.

Auxiliary components used in the sequence controller subsystem include altitude and impact sensing switches and necessary harnessing and cabling. These components have already been flight qualified and are available for use.

A functional block diagram of the sequence controller subsystem is shown in figure 1-3. As indicated, the sequence controller will control all parachute and recovery aid events during the recovery cycle. The recovery cycle will be initiated after SRM burnout and separation by enabling the sequence controller with a positive separation signal from the booster.

### 1.4.3 Recovery System Development Profile

In designing the parachute system, it is important to minimize the pressure loads on the parachutes and the gravitational acceleration impact loads on the SRM. For this reason a pilot chute and drogue chute precedes the main chute system, and reefing of the chutes is used to control loads. As shown in figure 1-4, the dynamic pressure and velocity is reduced incrementally so that main parachute deployment will occur below 150 psf dynamic pressure and 400 ft/sec.

The maximum skin temperature from aerodynamic heating as the SRM free falls is $500^{\circ}F$. Strength and reliability of the D6aC steel case is not affected until the temperature exceeds $1{,}000^{\circ}F$ (the steel case is tempered at $1{,}200^{\circ}F$).

### 1.4.4 SRM Attitude During Flotation

The SRM enters the water at approximately 63 ft/sec, and the impact load of approximately 5.8 g is absorbed by incremental loading on the nozzle and heat shield as the SRM submerges to a maximum depth of 40 ft. Water enters through

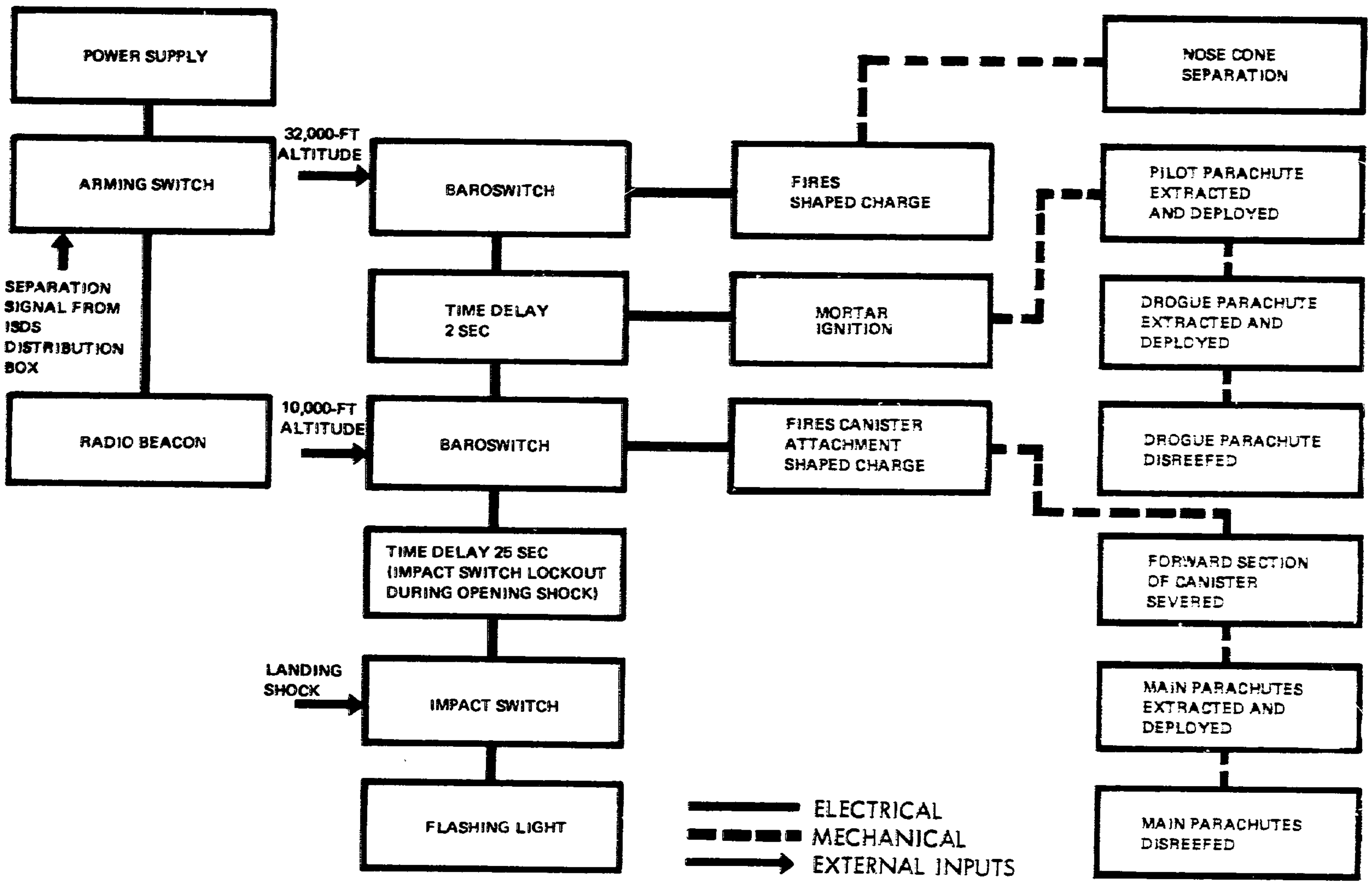


Figure 1-3. Parachute Sequence Controller

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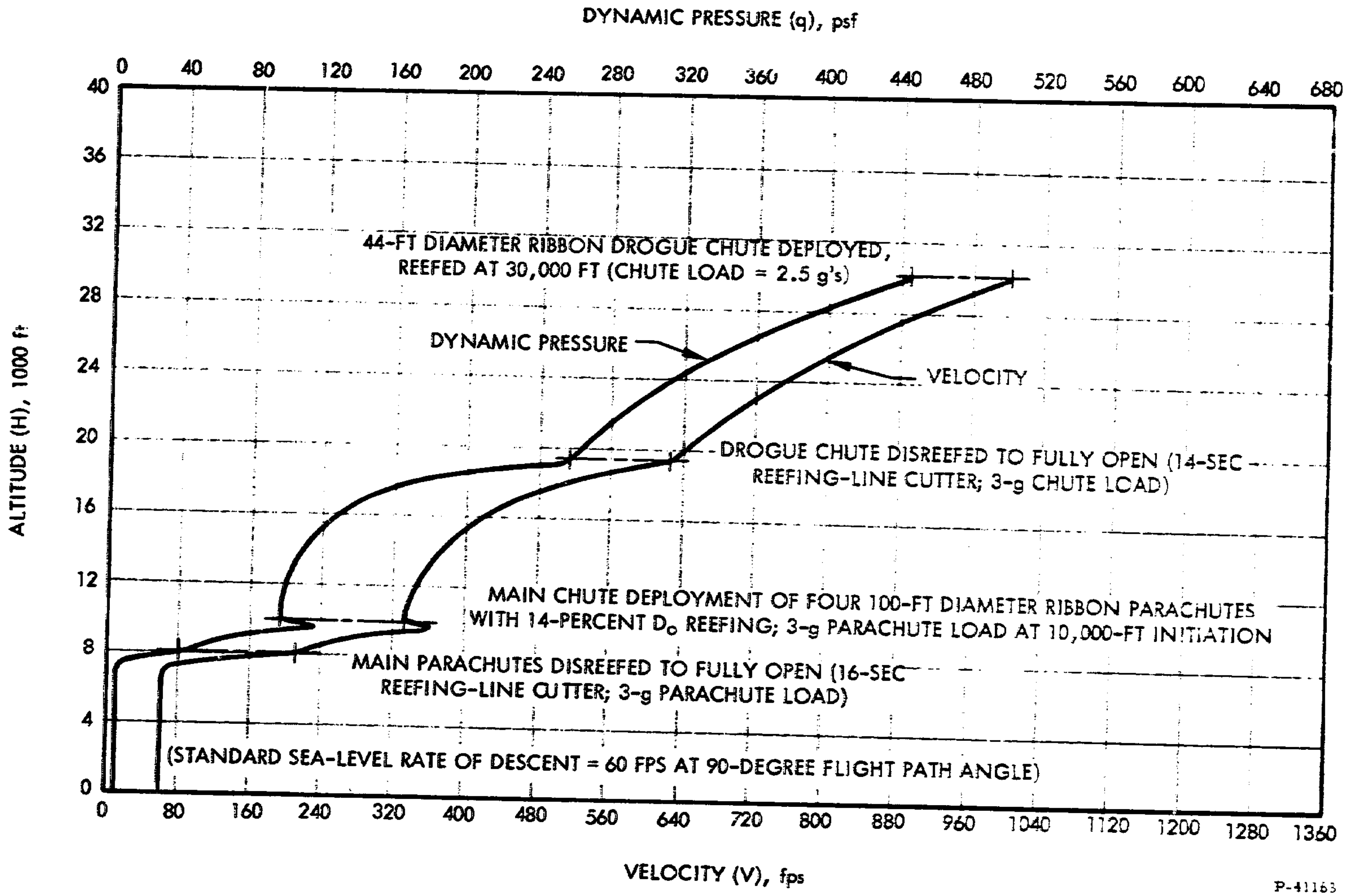


Figure 1-4. Recovery System Deployment Profile — Velocity vs Dynamic Pressure

the large nozzle to compress a large volume of air in the forward chamber. The SRM then comes to rest with the center of gravity well aft of the center of buoyancy, with the inclined nozzle down at about a 3- to 6-degree angle with the horizon (figure 1-5). The nozzle is submerged at this point and further entry of water is blocked.

As the LSD recovery vessel reaches the SRM, it offloads a small boat with two frogmen to strap on inflatable flotation rings to the fore and aft ends of the motor. These rings also facilitate flotation of the SRMs into the LSD and guard against damage to the SRM.

1.4.5 Parachute Container

The parachute container (figure 1-6) and nose cone replace the normal SRM nose cone. Weight of the parachute system is approximately 3,200 lb. Adequate space is available in the forward section for the complete parachute system; packaging presents no significant problem.

Preliminary design and stress analysis indicates that the maximum 3.5-g parachute impact load can be readily absorbed by the mounting structure and rings in the forward section of the SRM. Bending loads for canted SRM angles during parachute opening have been evaluated and present no major problem.

1.4.6 Segment and Closure Recovery Operations

Once the SRMs are loaded aboard the LSD, the motors are washed down with fresh water and dried using hot-air heaters (figure 1-7). The motors are offloaded at the Port Canaveral naval docks, disassembled at the center segment joint by removing the clevis pins, and trucked to the solid motor assembly area at Cape Kennedy. The motors are then fully disassembled, washed down with fresh water, and dried to remove all traces of salt water. The segments and closures are subjected to dimensional and NDT inspections. The MRB evaluates the inspection data and determines the acceptability of the segments and closures for refurbishment. Segments and closures which are acceptable are then adequately preserved and shipped to the UTC plant for refurbishment.

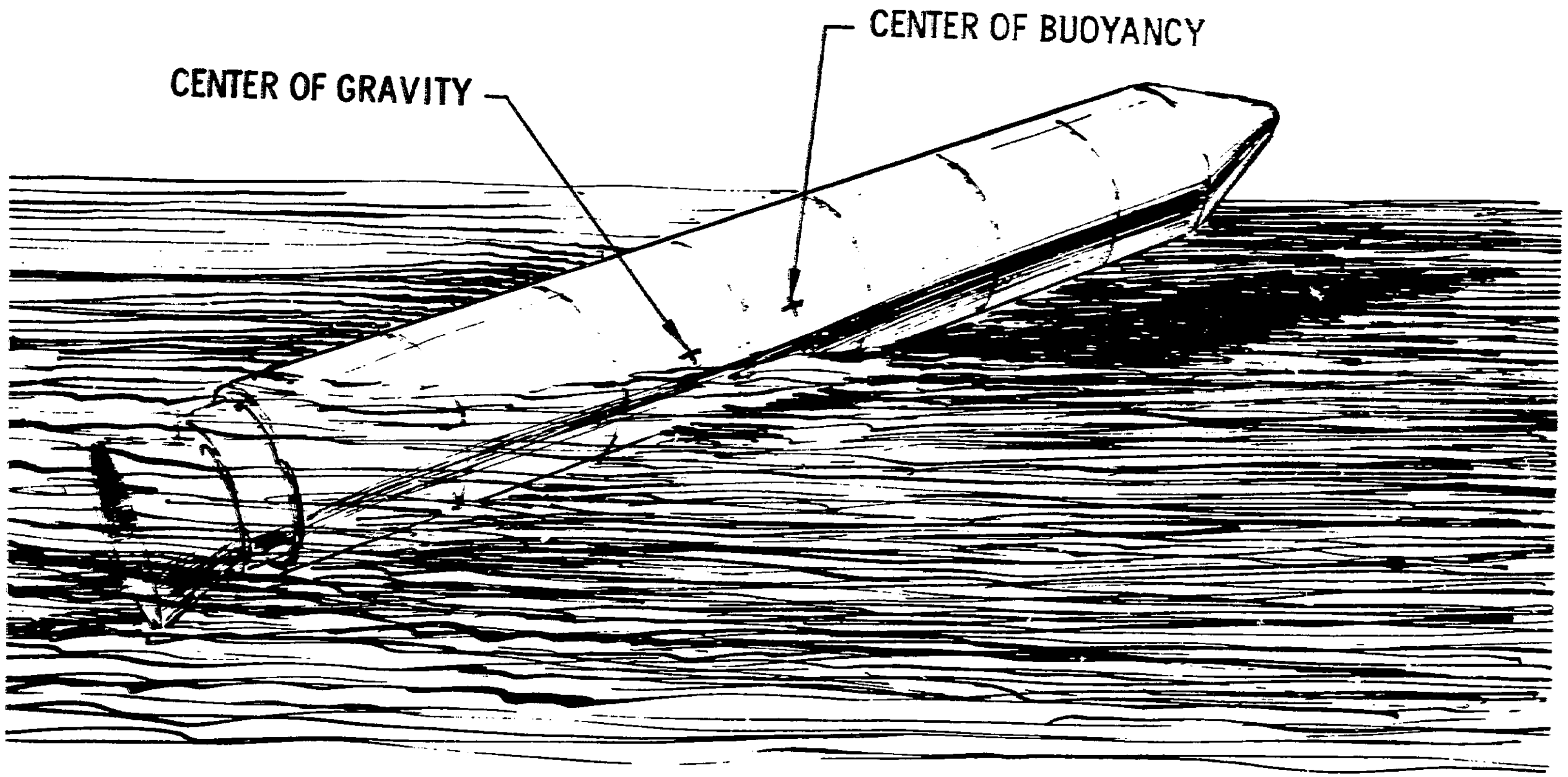


Figure 1-5. SRM Attitude During Flotation

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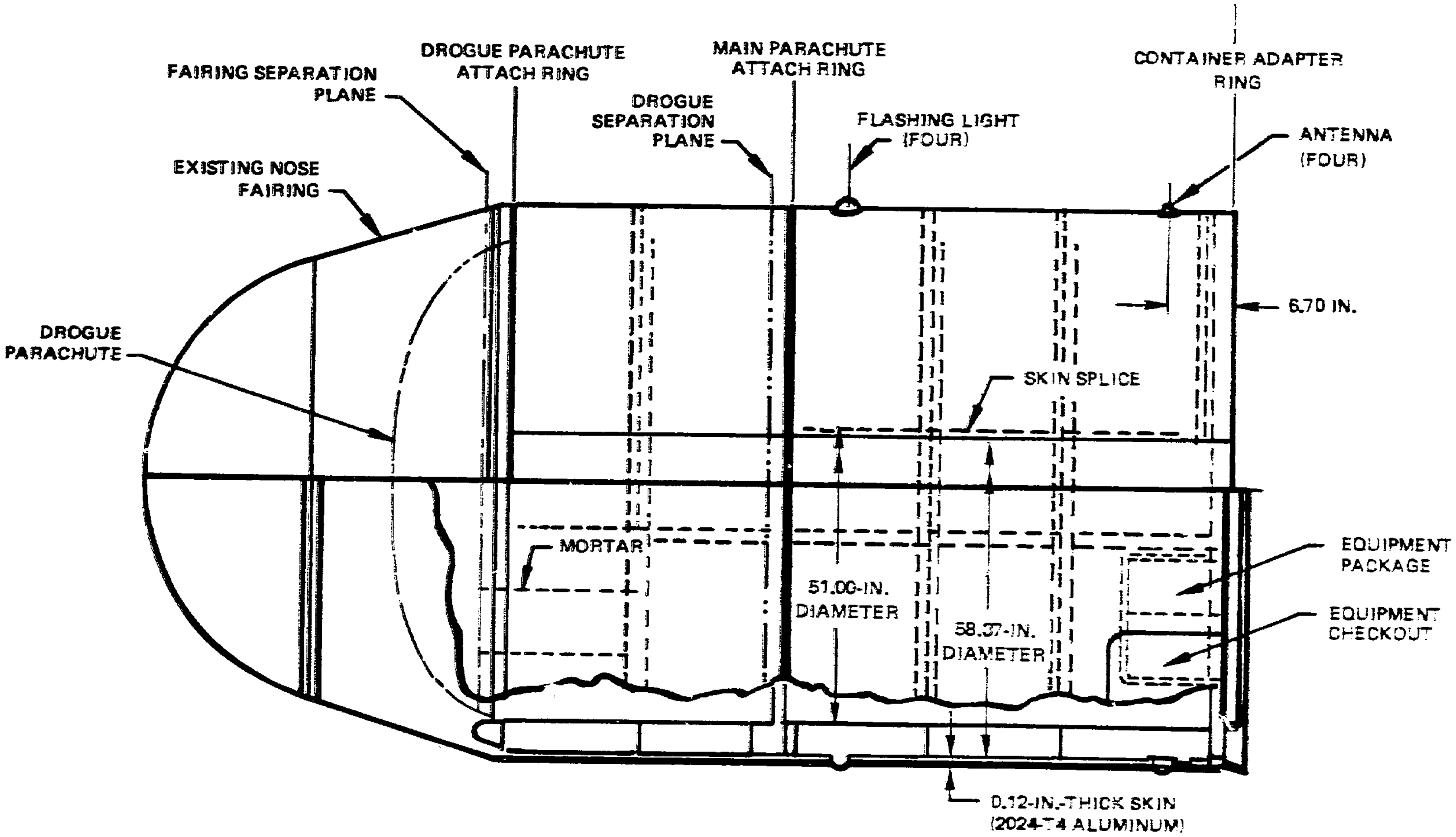


Figure 1-6. Parachute Container

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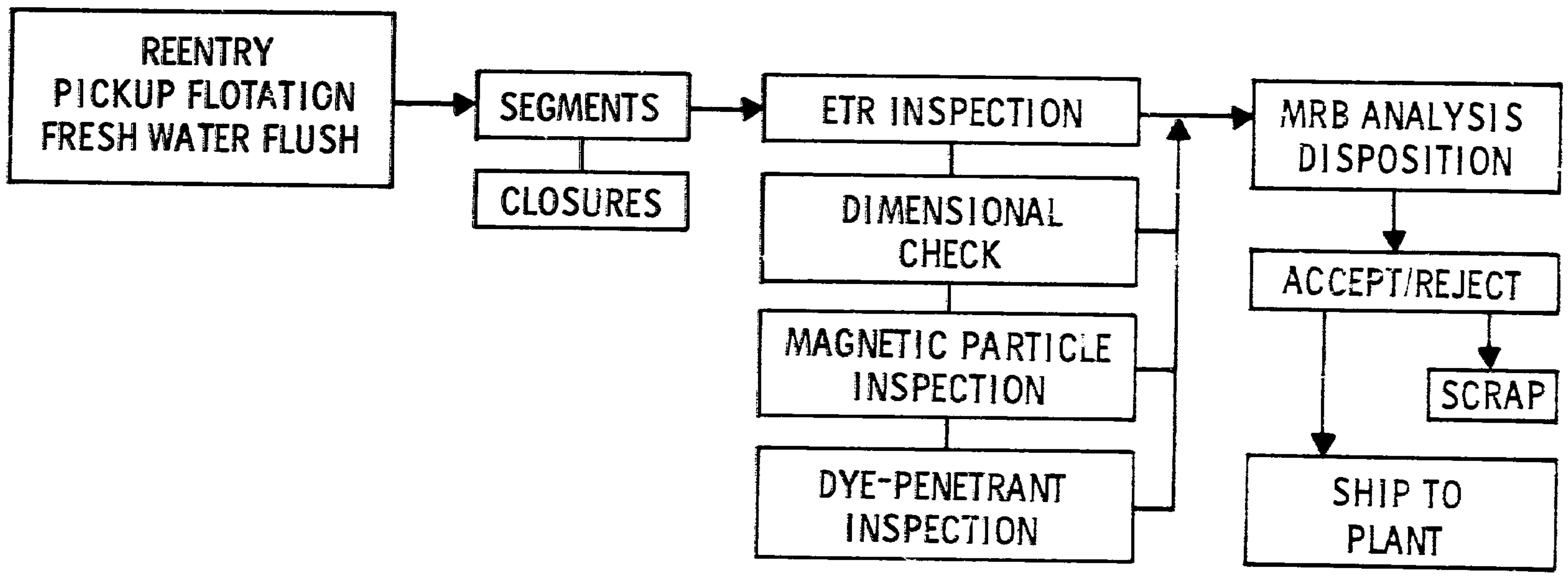


Figure 1-7. Segment and Closure Recovery Operations

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1.4.7 Segment and Closure Refurbishment

After recovery operations are completed at ETR, the SRMs are shipped to the refurbishment plant (figure 1-8). Activity for refurbishment consists of hardware cleanup, initial inspection for damage, and grit blast or rework as required. Segments and closures are then hydrotested to above MEOP to assume man-rating reliability. Final NDT consists of X-ray and magnetic particle inspections to locate any flaws or anomalies. The segments and closures are then reinsulated and enter the normal production-process cycle at UTC.

Forward and aft section hardware is not hydrotested but does receive complete NDT, X-ray, and magnetic particle inspections followed by spray coating with a protective sealant.

1.4.8 Segment and Closure Rehydrotest

The success of multiple motor case reuse is dependent upon the ability of the D6aC steel to withstand low cycle fatigue without rupture and to resist the effects of salt water corrosion. Low cycle fatigue failure can result if subcritical flaws in the metal grow with each cycle to critical size. However, a method of flaw evaluation has been developed to gain the full cyclic life of a pressure vessel.

This flaw evaluation method requires NDT inspection to ensure that there are no initial flaws of sufficient size to cause failure during the next flight operation. Also, to ensure recycle capability, the hydrotest pressure must be well below the case yield. From the table shown in figure 1-9, it can be seen that the proof test pressure is 14% below the case yield pressure, causing no permanent set or degradation in the material. Using these techniques between each operational cycle, the motor cases can withstand multiple reuse cycles with a high degree of reliability and confidence.

A UTC program was conducted in 1964 to determine the effects of unprotected D6aC steel immersed in salt water for up to 48 hr. It was found that for 48 hr, 0.002 in. of material removal was required. Under the present recovery time of 12 hr, the ratioed depth for removal of pits would allow the SRM hardware to be recycled 24 times and still leave a positive margin of safety for man-rating.

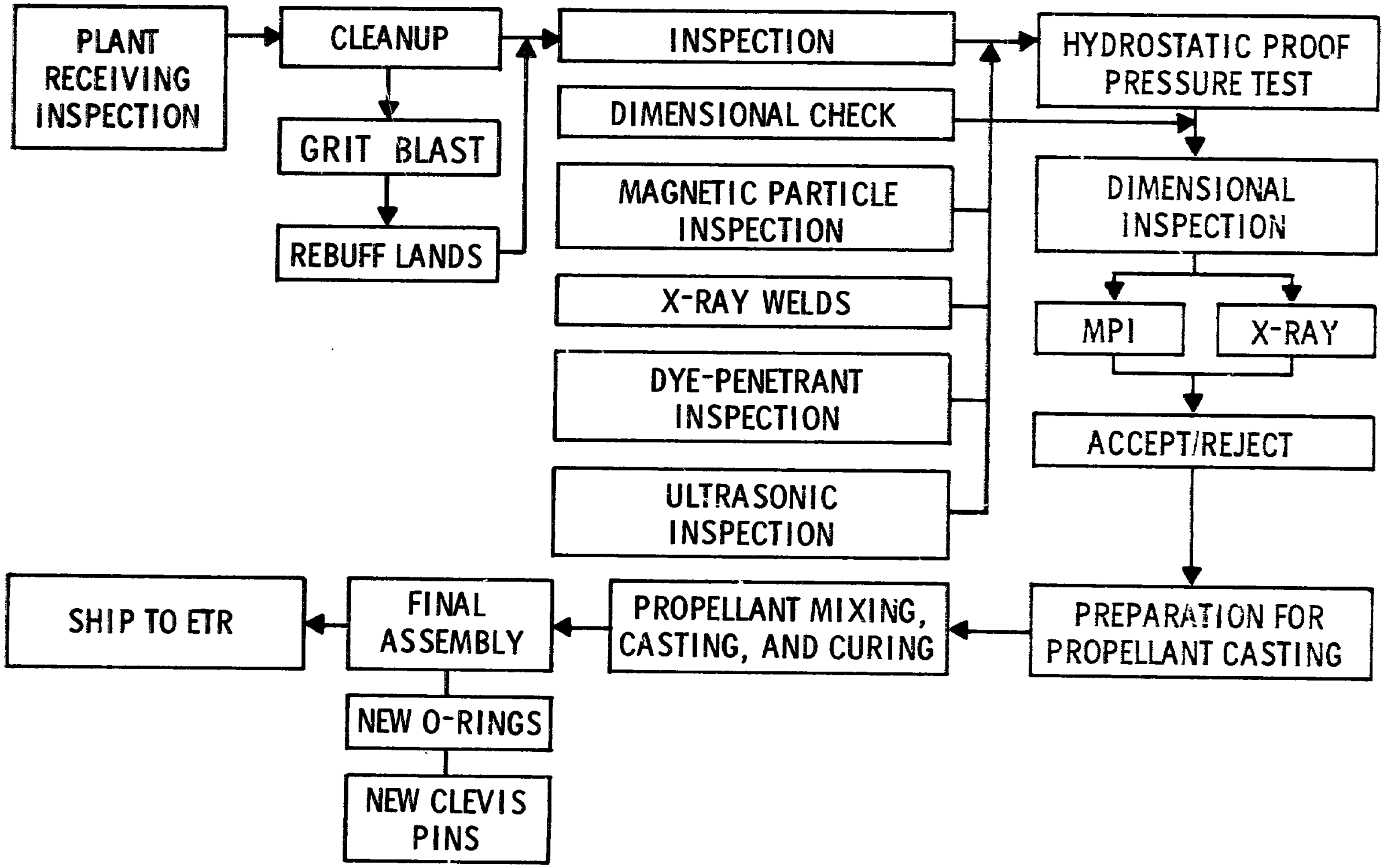


Figure 1-8. Segment and Closure Refurbishment

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| CONDITION | PRESSURE PSI |
|---|---|
| MEOP | 920 |
| PROOF | 975 |
| CASE YIELD | 1,137 |
| DESIGN CASE BURST | 1,265 |
| ACTUAL TEST BURST | 1,370 |

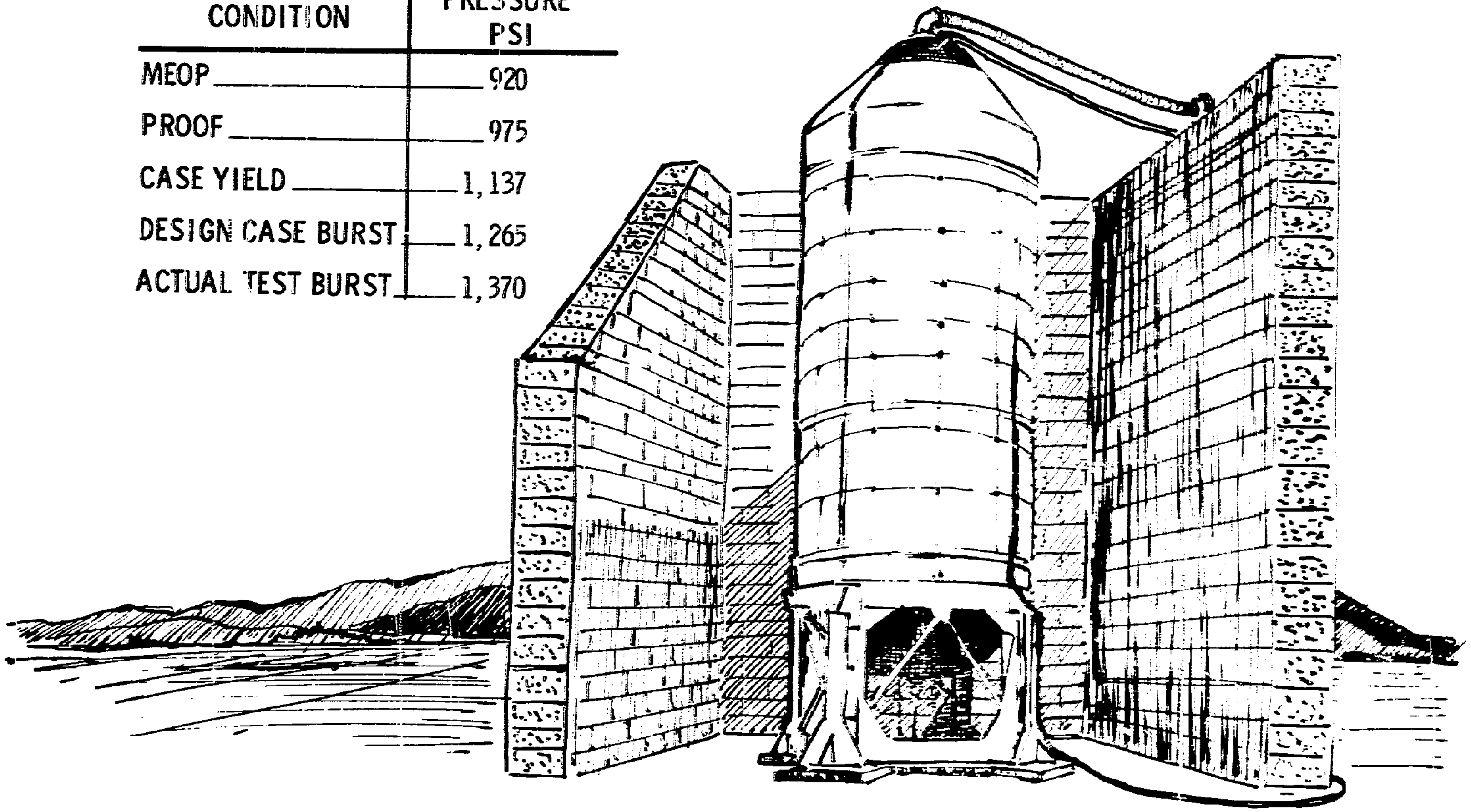

Figure 1-9. Segment Rehydrotest

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### 1.4.9 LSDs for Recovery

It is recommended that an LSD of the "Casa Grande" class be used for recovery of the SRMs (figure 1-10). These ships can readily load three 156-in.-diameter motors or six 120-in.-diameter motors. Two 50-ton cranes are mounted and movable on the sidedecks should they be needed. Cruise speed is 15 knots; a crew of 50 to 75 men is sufficient for short-term recovery action. Five of the ships are with the active U. S. Navy and six are "mothballed." It is estimated that a refurbished LSD can be obtained for about $3,000,000.

The LSD will begin tracking radio signals from the SRMs as they separate at an altitude of 180,000 ft. After impact the LSD will drop off a small boat containing two frogmen alongside each SRM. Inflatable flotation rings will be installed fore and aft on each SRM to facilitate flotation and to protect the SRM from damage.

The LSD has an 18-ft draft which will allow each SRM to be floated aboard. Fresh water on board will be used to wash down the SRMs.

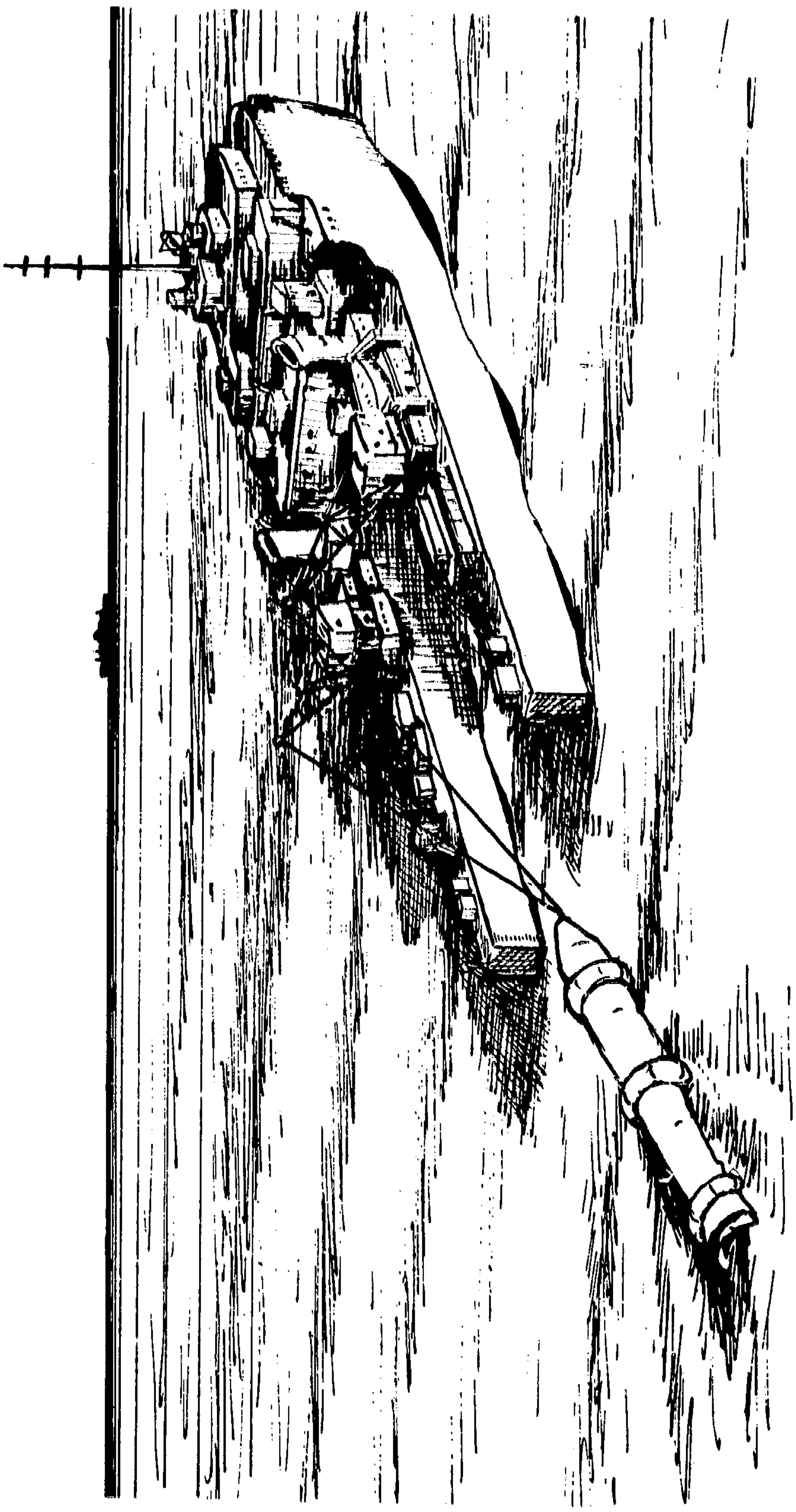

Figure 1-10. Landing Ship Dock

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# 2.0 COST ANALYSIS FOR RECOVERY OF THE SRM STAGE

## 2.1 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The cost savings, by mission model, which result from implementation of an SRM recovery program are presented in figure 2-1. This analysis shows major cost savings for each of the mission models and leads to the resulting conclusion that SRM recovery should be implemented in the Space Shuttle Program. This conclusion logically follows when the cost saving shown in figure 2-1 is compared with the nonrecurring cost of $6,797,000 shown in table 2-I. The relatively small nonrecurring cost for development (i.e., $6,797,000) will be amortized very early in the recovery program. The approximate cost saving resulting from recovery of SRMs then ranges from approximately 25% to 35% of the total SRM fabrication cost, depending upon mission model and quantity. Figures 2-2 and 2-3 clearly illustrate the cost incentive in booster hardware recovery.

Supporting information for these results is presented in the following pages and includes: considerations for parachute recovery system implementation; retrieval operations on the high seas; ETR acceptance and preparation of hardware for shipment to California; refurbishment of each SRM component; and delivery of all components to the UTC Development Center at Coyote, California, to reenter the normal process cycle for production of SRMs.

In concert with the latest emphasis on "prototype testing," UTC recommends immediate funding of $110,000 to conduct a full-scale drop test of one seven-segment SRM. This test would be conducted using full-scale seven-segment SRM hardware presently available at UTC, and could be conducted within 3 months after go-ahead. Flight velocity and impact loads would be achieved by dropping the SRM from the San Rafael-Richmond Bay Bridge into San Francisco Bay. Price quotations have been received from the San Francisco Bay Bridge Authority confirming these costs and the feasibility of the test. Such a test would serve to confirm the results of this recovery study very early in the program.

Although this cost analysis is based on no redesign of SRM components to effect recovery it should be noted that savings can be realized by redesign. In particular, if the electronic equipment is housed in shock-proof sealed containers, a savings increase of approximately 4% could be realized.

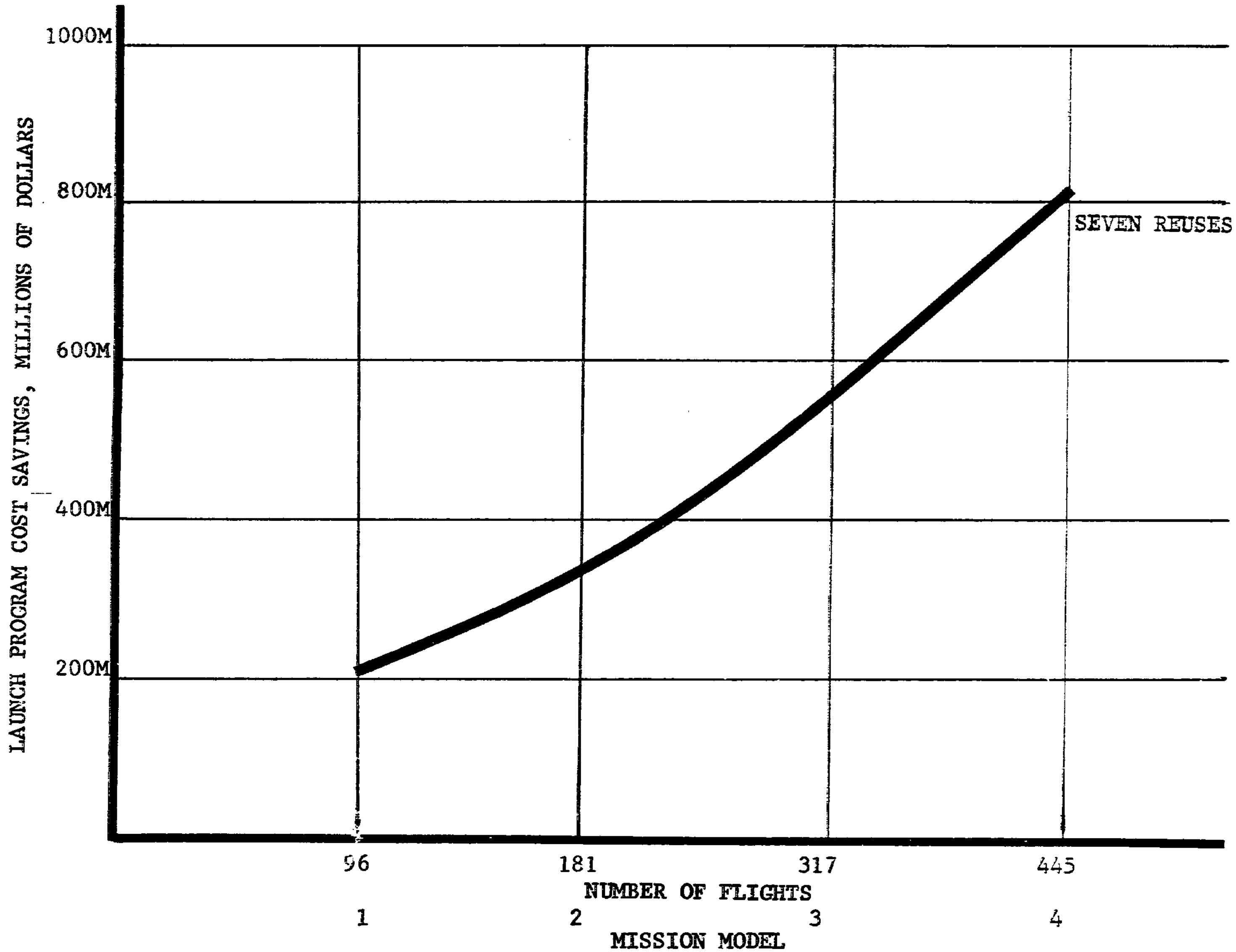


Figure 2-1. 120-In.-Diameter Parallel-Burn SRM Program Cost Savings to Recover and Reuse

TABLE 2-I

RECOVERY DEVELOPMENT PROGRAM
(Sheet 1 of 2)

SRM Hardware Modifications to Incorporate Parachute System

| Modification | Cost |
|---|---|
| Design, canister, and nose cone | $ 80,000 |
| Tooling for new canister | 100,000 |
| Tooling for new nose cone | 80,000 |
| Fabrication of four development units | 130,000 |
| Structural testing of nose cone and canister | 180,000 |
| Parachute development (modifications) | 2,220,000 |
| Modifications and bench testing of sequence controller and location aids | 200,000 |
| Linear-shaped charge design and qualification | 130,000 |
| Aneroid sensor modifications | 20,000 |
| System integration | 80,000 |
| | $3,220,000 |

Other Nonrecurring Costs for Recovery

| Item | Cost |
|---|---|
| Crane and dock modifications at ETR | $ 600,000 |
| Handling — rings and equipment | 150,000 |
| LSD recovery modifications (fresh-water hoses, tiedowns, etc.) | 220,000 |
| Flotation collars (inflatable) | 250,000 |
| Nozzle plug for recovery | 8,000 |
| Special disassembly and cleanup tooling | 100,000 |
| Special refurbishment tooling | 100,000 |
| Tooling and spray equipment for protective coating | 80,000 |
| Miscellaneous | 120,000 |
| | $1,628,000 |

TABLE 2-1

RECOVERY DEVELOPMENT PROGRAM
(Sheet 2 of 2)

Development Demonstration Program

| Item | Cost |
|---|---|
| SRM impact test (water entry at 60 ft/sec) to verify component survivability (existing motor hardware to be used) | $110,000 |
| SRM water flotation tests to verify and evaluate the flotation attitude, stability, leakage characteristics, pickup requirements, and the effects of surface wave action | 50,000 |
| Evaluation of LSD recovery operations | 100,000 |
| Tests to verify that shock loads resulting from water entry at 60 ft/sec do not ignite the safe-and-arm pyrotechnics for the destruct and thrust termination system | 14,000 |
| Tests to evaluate the effect of salt water, salt-water spray, and corrosion on SRM components | 42,000 |
| Evaluation of protective coatings for SRM hardware | 68,000 |
| Air drop tests of the parachute recovery system using dummy payloads (or 1200-series motors) | 1,220,000 |
| Multiple hydrotesting of three segments and two closures to establish multiple reuse reliability (existing seven-segment test hardware to be used) | 45,000 |
| Motion picture coverage of the next Titan III launch to evaluate SRM postseparation dynamics | 20,000 |
| Nozzle impact load testing to verify action of the actuators and failure mode of the extension core | 190,000 |
| Model testing, analytical studies, and specimen testing to direct, support, and supplement these demonstrations and to evaluate the specific recovery system | 90,000 |
| | $1,949,000 |
| Total development and nonrecurring cost | $6,797,000 |

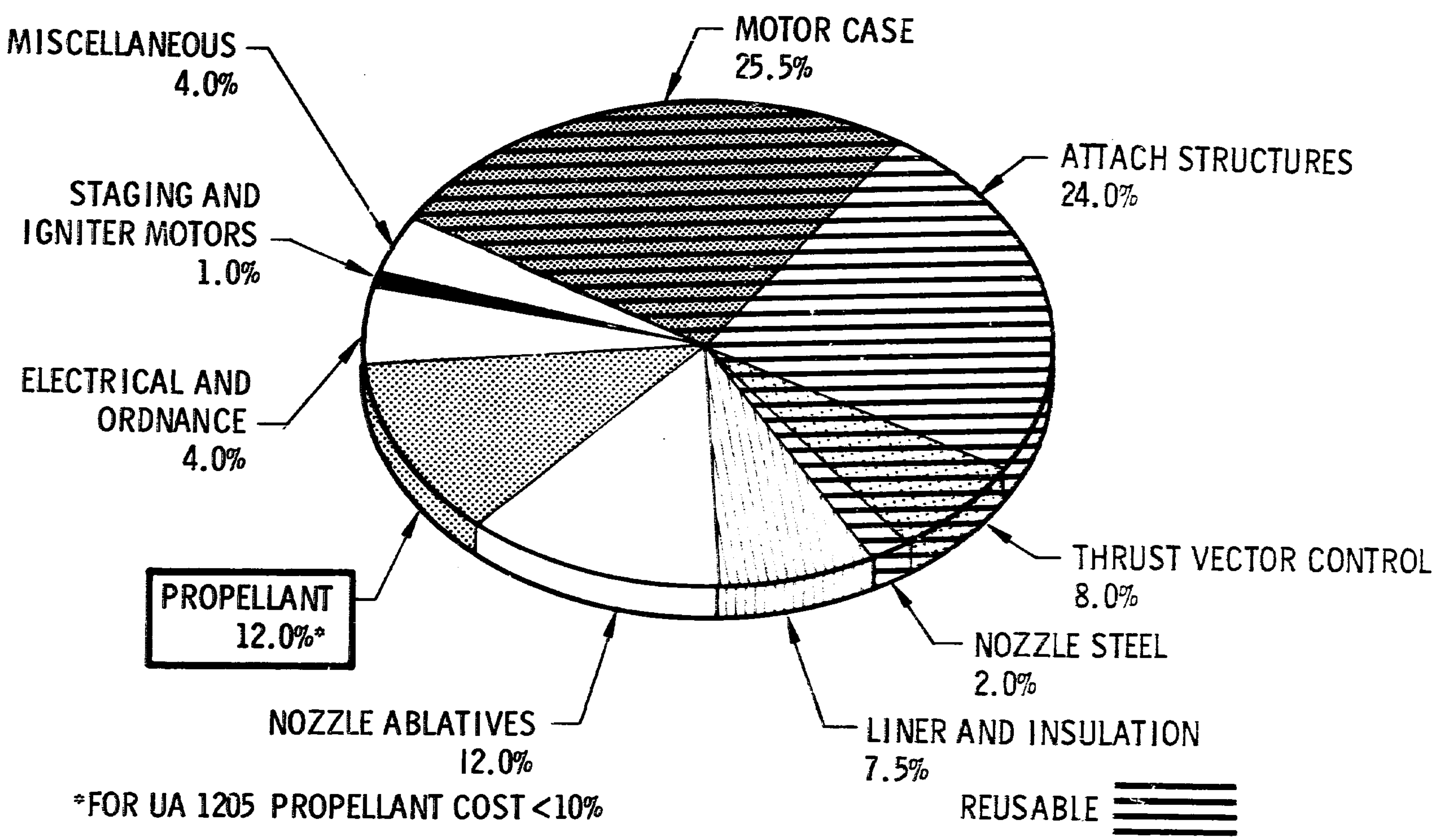


Figure 2-2. Typical SRM Hardware Cost Percentages

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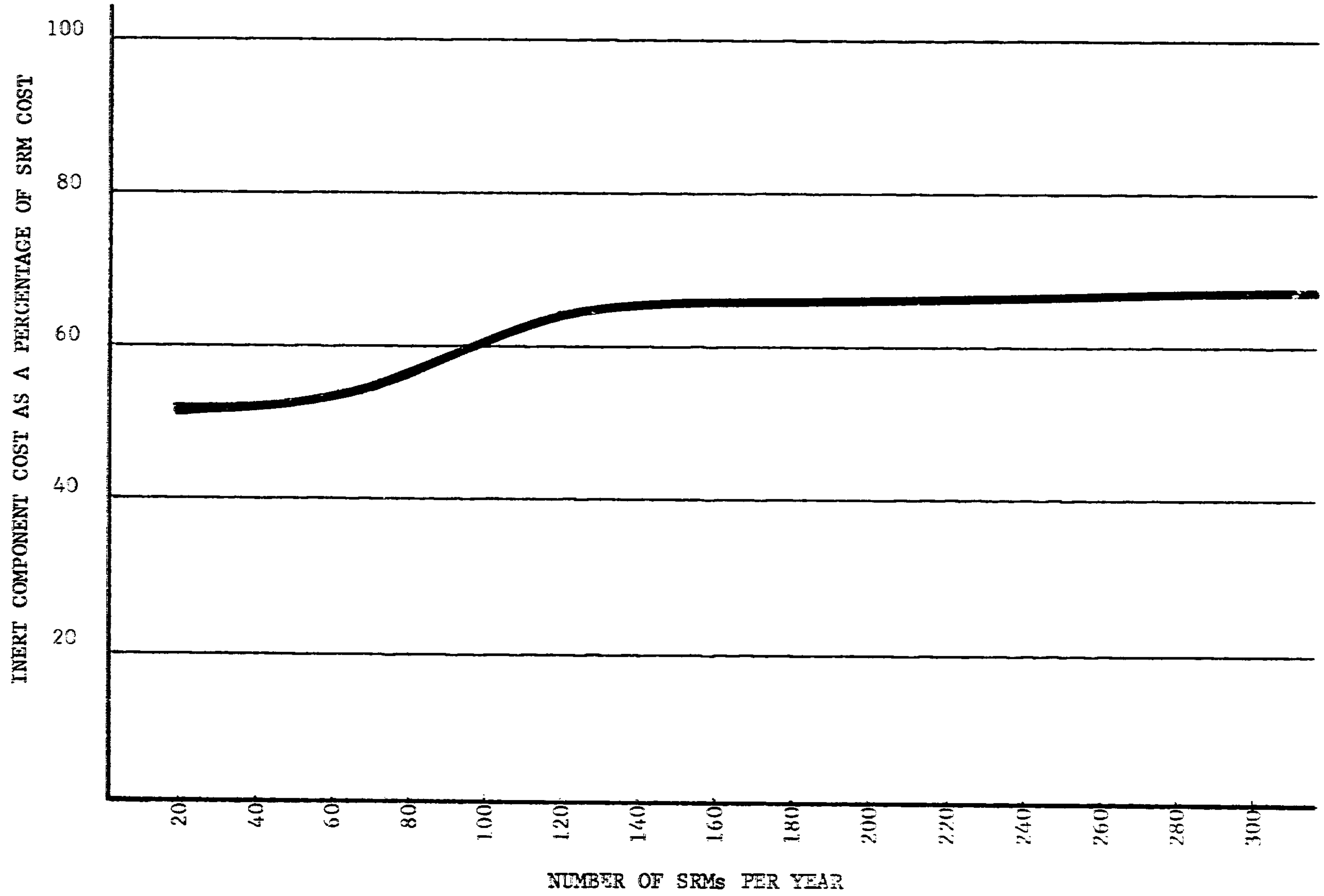


Figure 2-3. 120-In.-Diameter Parallel-Burn SRM Inert Component Cost as a Percentage of SRM Cost

## 2.2 GROUND RULES AND ASSUMPTIONS

The costs presented herein are based on the following ground rules and assumptions:

A. The number of flights are based on four space shuttle mission models as follows:

| Mission Model | Number of Flights |
|---|---|
| 1 | 445 |
| 2 | 317 |
| 3 | 118 |
| 4 | 96 |

B. Four 120-in.-diameter SRMs are required per flight

C. Costs are calculated based on the value of the dollar in 1970

D. Launches are from ETR

E. No new design of the SRM is required to implement recovery, except for the incorporation of a parachute system in the forward nose cone and the addition of one nozzle shock absorber

F. Only major components of the SRM need to be recovered to effect a savings of 65% of the total inert cost per SRM

G. Attrition rate for recovered SRM components ranges from 16% to 25%

H. Major SRM components can be refurbished and reused seven times

I. The variation in SRM component cost versus quantity ordered is approximately as shown in figure 2-4

J. Recovered hardware is picked up by LSD and washed down with fresh water; cranes then offload the hardware onto trucks which deliver it to the UTC disassembly and inspection area at ETR

K. Costs for shipment of hardware are included (no Government bill of lading assumed)

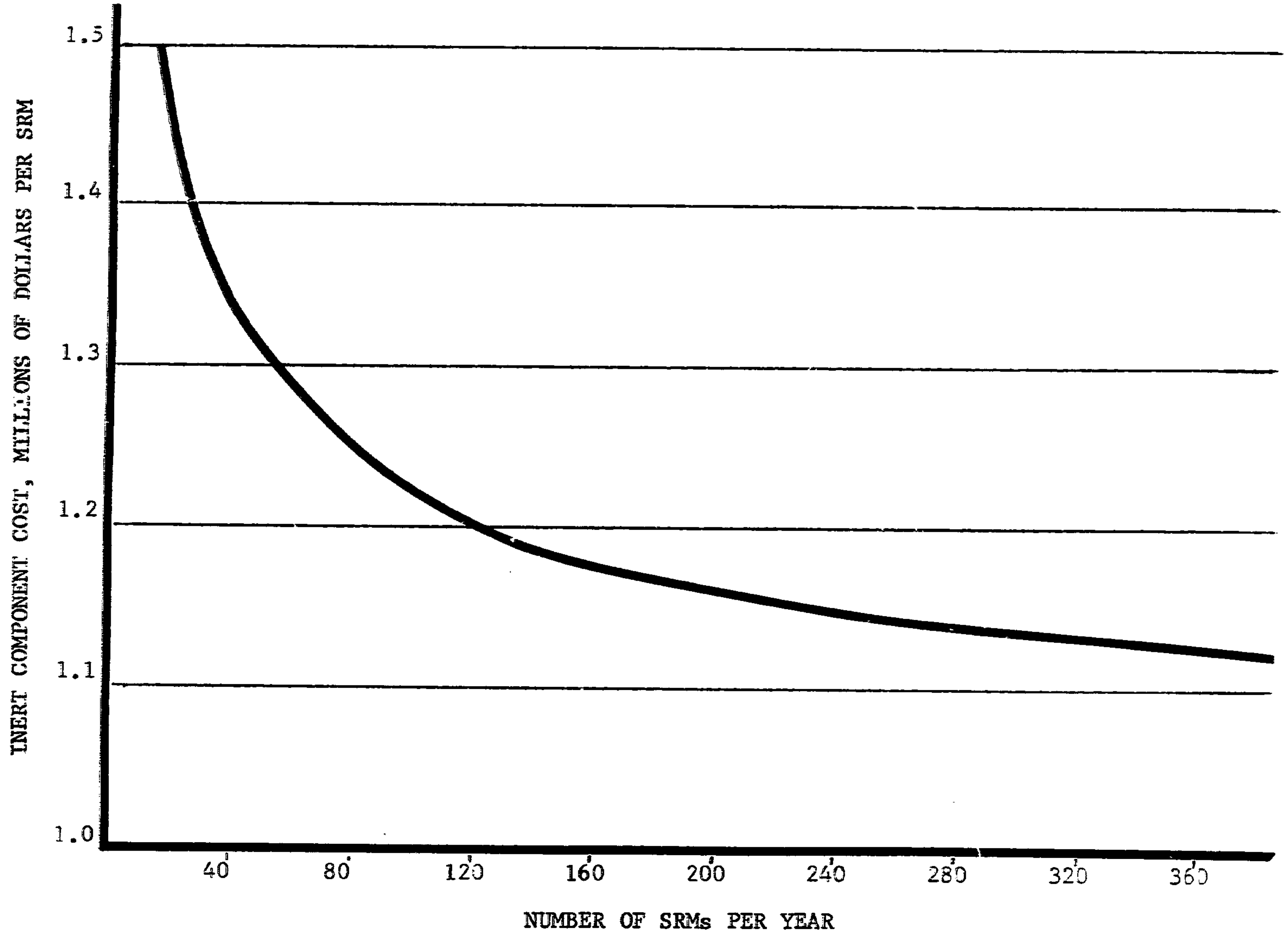


Figure 2-4. 120-In.-Diameter Parallel-Burn SRM
Inert Component Cost Reduction vs Quantity

L. LSD recovery of four SRMs includes a 100-man crew operating the ship at $20/man/hr for 32 hr, and special equipment and frogmen to be on station and enroute (recovery details are presented in table 2-II)

M. Hardware items recovered and items not recovered are shown in figures 2-5 through 2-8 for each of the mission models

N. Refurbishment of hardware will take place in California; shipment from ETR to California is $13,000 per SRM (no Government bill of lading assumed).

TABLE 2-II

RECOVERY COST

| Recovery Operation | Time | Mission Model No. 4 (96 Flights) | Mission Model No. 1 (445 Flights) |
|---|---|---|---|
| Parachute system | – | $ 95,000 | $ 80,000 |
| Nozzle shock absorber | – | 10,000 | 8,200 |
| Retrieval system | | | |
| LSD preparation or rental | – | 5,000 | 5,000 |
| 100-man crew for LSD | | | |
| Dock to splashdown station, hr | 6 | 3,000 | 2,460 |
| At splashdown station, hr | 20 | 40,000 | 8,200 |
| Towing to dock, hr | 6 | 3,000 | 2,460 |
| Unloading and delivery to SMAB, man-hours | 50 | 1,250 | 1,025 |
| Cleanup and inspection for damage, man-hours | 580 | 14,500 | 11,900 |
| Packaging for shipment, man-hours | 50 | 1,250 | 1,025 |
| Total recovery (per SRM) | | $143,000 | $120,4[illegible]0 |

## 2.3 COST ELEMENTS

### 2.3.1 Cost of New SRM

The cost figures for new SRM hardware presented in figures 2-5 through 2-8 are based on recent vendor quotes for this study and on actual cost data

P-120" Diameter
7 Segment SRMs
445 Flights

| Inert Items Reusable | All New Hardware Quantity | Hardware Recycled Seven Times + Attrition Quantity + Attrition | Recovery and Refurbishment Seven Times Recovery | Refurbishment | Shipping |
|---|---|---|---|---|---|
| Segments | 12,460 | 1,560 + 16% = 1,810 | | | |
| Forward Closure | 1,780 | 223 + 16% = 259 | | | |
| Aft Closure | 1,780 | 223 + 16% = 259 | | | |
| Aft Skirt | 1,780 | 223 + 16% = 259 | | | |
| Nozzle Steel | 1,730 | 223 + 16% = 259 | | | |
| Forward Thrust Skirt | 1,730 | 223 + 16% = 259 | | | |
| Nose Section | 1,780 | 223 + 16% = 259 | | | |
| TECHROLL Seal Hydraulics | 1,780 | 223 + 16% = 259 | | | |
| TECHROLL Seal Actuators | 1,780 | 223 + 16% = 259 | | | |
| Igniter Motor | 1,780 | 223 + 16% = 259 | | | |
| ISDS and Bridgewire Ordnance | 1,780 | 223 + 25% = 279 | | | |
| Raceways | 1,780 | 223 + 25% = 279 | | | |
| COST | $1,400 | $254 | $187 | $124 | $10<br>$331 |
| **Inert Items Not Reusable** | | | | | |
| Heat Shield | 1,780 | No Reuse | Not Applicable | | |
| Nozzle Exit Cone | 1,780 | No Reuse | Not Applicable | | |
| Nozzle Ablatives | 1,780 | No Reuse | Not Applicable | | |
| Nose Cap | 1,780 | No Reuse | Not Applicable | | |
| Bridgewire and Ordnance | 1,780 | No Reuse | Not Applicable | | |
| Batteries and Cables | 1,780 | No Reuse | Not Applicable | | |
| Staging Motors | 1,780 | No Reuse | Not Applicable | | |
| Motor Insulation | 1,730 | No Reuse | Not Applicable | | |
| Other Miscellaneous Inerts | 1,730 | No Reuse | Not Applicable | | |
| COST | $693 | $693 | | | |
| Total Cost of Inerts | $2,093 | $947 | | | $331 |

* Dollar Values Given in Millions

Total Cost Savings of $815 Million

Figure 2-5. Program Savings Based on Recovery of SRM Hardware

P-120" Diameter
7 Segment SRMs
317 Flights

| | All New Hardware | Hardware Recycled Seven Times + Attrition | Recovery and Refurbishment Seven Times | | |
|---|---|---|---|---|---|
| Inert Items Reusable | Quantity | Quantity + Attrition | Recovery | Refurbishment | Shipping |
| Segments | 8,876 | 1,112 + 16% = 1,290 | | | |
| Forward Closure | 1,268 | 159 + 16% = 185 | | | |
| Aft Closure | 1,268 | 159 + 16% = 185 | | | |
| Aft Skirt | 1,268 | 159 + 16% = 185 | | | |
| Nozzle Steel | 1,268 | 159 + 16% = 185 | | | |
| Forward Thrust Skirt | 1,268 | 159 + 16% = 185 | | | |
| Nose Section | 1,268 | 159 + 25% = 199 | | | |
| TECHROLL Seal Hydraulics | 1,268 | 159 + 25% = 199 | | | |
| TECHROLL Seal Actuators | 1,268 | 159 + 25% = 199 | | | |
| Igniter Motor | 1,268 | 159 + 16% = 185 | | | |
| ISDS and Bridgewire Ordnance | 1,268 | 159 + 16% = 185 | | | |
| Raceways | 1,268 | 159 + 16% = 185 | | | |
| COST | $1,030 | $182 | $143.5 | $94.4 | $14.5<br>$252.4 |
| Inert Items Not Reusable | | | | | |
| Heat Shield | 1,268 | No Reuse | | Not Applicable | |
| Nozzle Exit Cone | 1,268 | No Reuse | | Not Applicable | |
| Nozzle Ablatives | 1,268 | No Reuse | | Not Applicable | |
| Nose Cap | 1,268 | No Reuse | | Not Applicable | |
| Bridgewire and Ordnance | 1,268 | No Reuse | | Not Applicable | |
| Batteries and Cables | 1,268 | No Reuse | | Not Applicable | |
| Staging Motors | 1,268 | No Reuse | | Not Applicable | |
| Motor Insulation | 1,268 | No Reuse | | Not Applicable | |
| Other Miscellaneous Inerts | 1,268 | No Reuse | | Not Applicable | |
| COST | $505 | $492 | | | |
| Total Cost of Inerts | $1,535 | $674 | | | $252.4 |

* Dollar Values Given in Millions

Total Cost Savings of $609 Million

Figure 2-6. Program Savings Based on Recovery of SRM Hardware

P-120" Diameter
7 Segment SRMs
181 Flights

| | All New Hardware | Hardware Recycled Seven Times + Attrition | Recovery and Refurbishment Seven Times | | |
|---|---|---|---|---|---|
| Inert Items Reusable | Quantity | Quantity + Attrition | Recovery | Refurbishment | Shipping |
| Segments | 5,068 | 635 + 16% = 7,370 | | | |
| Forward Closure | 724 | 91 + 16% = 106 | | | |
| Aft Closure | 724 | 91 + 16% = 106 | | | |
| Aft Skirt | 724 | 91 + 16% = 106 | | | |
| Nozzle Steel | 724 | 91 + 16% = 106 | | | |
| Forward Thrust Skirt | 724 | 91 + 16% = 106 | | | |
| Nose Section | 724 | 91 + 25% = 114 | | | |
| TECHROLL Seal Hydraulics | 724 | 91 + 25% = 114 | | | |
| TECHROLL Seal Actuators | 724 | 91 + 25% = 114 | | | |
| Igniter Motor | 724 | 91 + 16% = 106 | | | |
| ISDS and Bridgewire Ordnance | 724 | 91 + 25% = 114 | | | |
| Raceways | 724 | 91 + 25% = 114 | | | |
| COST | $606 | $104 | $87.5 | $58.0 | $8.27<br>$153.8 |
| Inert Items Not Reusable | | | | | |
| Heat Shield | 724 | No Reuse | Not Applicable | | |
| Nozzle Exit Cone | 724 | No Reuse | Not Applicable | | |
| Nozzle Ablatives | 724 | No Reuse | Not Applicable | | |
| Nose Cap | 724 | No Reuse | Not Applicable | | |
| Bridgewire and Ordnance | 724 | No Reuse | Not Applicable | | |
| Batteries and Cables | 724 | No Reuse | Not Applicable | | |
| Staging Motors | 724 | No Reuse | Not Applicable | | |
| Motor Insulation | 724 | No Reuse | Not Applicable | | |
| Other Miscellaneous Inerts | 724 | No Reuse | Not Applicable | | |
| COST | $296 | $296 | | | |
| Total Cost of Inerts | $902 | $400 | | | $153.8 |

* Dollar Values Given in Millions

**Total Cost Savings of $348 Million**

Figure 2-7. Program Savings Based on Recovery of SRM Hardware

| P-120" Diameter<br>7 Segment SRMs<br>96 Flights | All New Hardware | Hardware Recycled Seven Times + Attrition | Recovery and Refurbishment Seven Times | | |
|---|---|---|---|---|---|
| **Inert Items Reusable** | Quantity | Quantity + Attrition | Recovery | Refurbishment | Shipping |
| Segments | 2,688 | 336 + 16% = 390 | | | |
| Forward Closure | 384 | 48 + 16% = 56 | | | |
| Aft Closure | 384 | 48 + 16% = 56 | | | |
| Aft Skirt | 384 | 48 + 16% = 56 | | | |
| Nozzle Steel | 384 | 48 + 16% = 56 | | | |
| Forward Thrust Skirt | 384 | 48 + 16% = 56 | | | |
| Nose Section | 384 | 48 + 25% = 60 | | | |
| TECHROLL Seal Hydraulics | 384 | 48 + 25% = 60 | | | |
| TECHROLL Seal Actuators | 384 | 48 + 25% = 60 | | | |
| Igniter Motor | 384 | 48 + 16% = 56 | | | |
| ISDS and Bridgewire Ordnance | 384 | 48 + 16% = 60 | | | |
| Raceways | 384 | 48 + 16% = 60 | | | |
| COST | $347.0 | $55.2 | $48.0 | $32.0 | $4.37<br>$84.37 |
| **Inert Items Not Reusable** | | | | | |
| Heat Shield | 384 | No Reuse | | Not Applicable | |
| Nozzle Exit Cone | 384 | No Reuse | | Not Applicable | |
| Nozzle Ablatives | 384 | No Reuse | | Not Applicable | |
| Nose Cap | 384 | No Reuse | | Not Applicable | |
| Bridgewire and Ordnance | 384 | No Reuse | | Not Applicable | |
| Batteries and Cables | 384 | No Reuse | | Not Applicable | |
| Staging Motors | 384 | No Reuse | | Not Applicable | |
| Motor Insulation | 384 | No Reuse | | Not Applicable | |
| Other Miscellaneous Inerts | 384 | No Reuse | | Not Applicable | |
| COST | $165.3 | $165.3 | | | |
| Total Cost of Inerts | $510.5 | $218.7 | | | $84.37 |

* Dollar Values Given in Millions

Total Cost Savings of $207 Million

Figure 2-8. Program Savings Based on Recovery of SRM Hardware

accumulated during the past 9 years on the Titan III Program for 120-in.-diameter SRM hardware. Variations in unit prices with changes in quantity were determined by contacting the present vendors for Titan III 120-in.-diameter SRM hardware; these results are presented in figure 2-4.

### 2.3.2 Cost of Hardware Based on Recycling

When components are recycled seven times, a large cost saving results because of the reduced quantities ordered; however, the unit price of these components at the reduced quantities increases significantly. This is shown in figure 2-4. Also, an attrition rate must be added to the components ordered to account for recovery losses and quality control rejections. For the hardware in this costing, attrition rates vary from 16% to 25%, as shown in figures 2-5 through 2-8. These attrition rates cover all hardware losses during recovery and refurbishment operations, including quality control rejections.

### 2.3.3 Cost of Recovery and Refurbishment

A. Recovery

The recovery cost elements are shown in table 2-II and include a 100-man LSD crew operating for 20 hr in the splashdown area to recover four SRMs. Time to and from the splashdown area is also included at 6 hr each way. Frogmen are included in the LSD crew to perform in-water operations around the SRMs. The SRMs will be washed down with fresh water on the LSD and then delivered to the Naval docks at ETR for offloading by crane onto flat-bed trucks. The trucks will then deliver the hardware to the UTC disassembly and inspection area at ETR. The washdown and disassembly will be followed by application of protective coatings and shipment to California. It is estimated that the cost of an LSD of the "Casa Grande" class will be approximately $3,000,000, should it be desirable to purchase one outright. At this time, five of these ships are in the active U.S. Navy and six are "mothballed". The rental cost, included in the recovery expense, is sufficient to purchase one LSD.

B. Refurbishment

After the recovery operation is completed, the SRM components are shipped to California for refurbishment. The refurbishment operation for each component is shown in table 2-III. After cleaning and inspection, the case segments and closures are hydrotested and magnetic particle inspected. The hardware is then reinsulated and enters the normal production cycle for propellant loading, assembly, and buyoff at the UTC Development Center, Coyote, California.

C. Shipment

Shipment cost for one SRM from ETR to California is $13,000. This cost is included for all recycled hardware. Government bill of lading is not considered for purposes of this study.

## 2.4 OTHER CONSIDERATIONS

Although this study is based primarily on the reuse and recycle of hardware seven times, it should be noted that it is completely feasible to recycle hardware many more times. Figure 2-9 shows the additional cost saving with up to 100 reuses of hardware. These costs must, however, include much higher attrition rates as the reuse of hardware increases; e.g., for the 100-reuse curve, attrition rates up to 42% for some components are included.

TABLE 2-III

REFURBISHMENT COST

| Refurbishment Operation | Man-hours | Cost/SRM Mission Model No. 4 (96 Flights) | Cost/SRM Launch Model No. 1 (445 Flights) |
|---|---|---|---|
| Shipment from ETR to California | — | $ 13,000 | $ 13,000 |
| Refurbishment of Segments and Closures | | | |
| Receiving inspection | 50 | 1,250 | 1,025 |
| Remove insulation | 468 | 11,700 | 9,600 |
| Sandblast | 38 | 937 | 842 |
| Full MPI | 38 | 937 | 842 |
| Hydrotest | 150 | 3,750 | 3,075 |
| Full MPI | 38 | 937 | 842 |
| Full quality control acceptance | 75 | 1,875 | 1,537 |
| Paint and protect surfaces | 62 | 1,562 | 1,280 |
| Delivery for insulation | — | 125 | 100 |
| Material | — | 4,000 | 3,275 |
| Handling | — | 1,250 | 1,025 |
| Liaison support | 140 | 3,500 | 2,900 |
| Refurbishment of nose section foward and aft skirts | | | |
| Receiving inspection | 40 | 1,000 | 820 |
| Remove protective coating | 100 | 2,500 | 2,050 |
| Clean and passivate | 200 | 5,000 | 4,100 |
| Full MPI | 100 | 2,500 | 2,050 |
| Dimensional inspection | 100 | 2,500 | 2,050 |
| Paint and apply protective coating and external insulation | 500 | 12,500 | 10,200 |
| Full quality control acceptance | 100 | 2,500 | 2,050 |
| Materials | — | 14,000 | 11,500 |
| Handling | — | 1,200 | 1,000 |
| Liaison support | 160 | 4,000 | 3,300 |
| Refurbishment of other motor components (igniters, hydraulic and actuator systems, parachute canister, nozzle steel and ISDS) | | | |
| Inspection, clean, passivate, MPI, paint, and quality control acceptance | 500 | 12,500 | 10,200 |
| Materials and handling | — | 2,000 | 1,600 |
| Liaison support | 55 | 1,700 | 1,400 |
| Total refurbishment (per SRM) | | $108,723 | $91,663 |

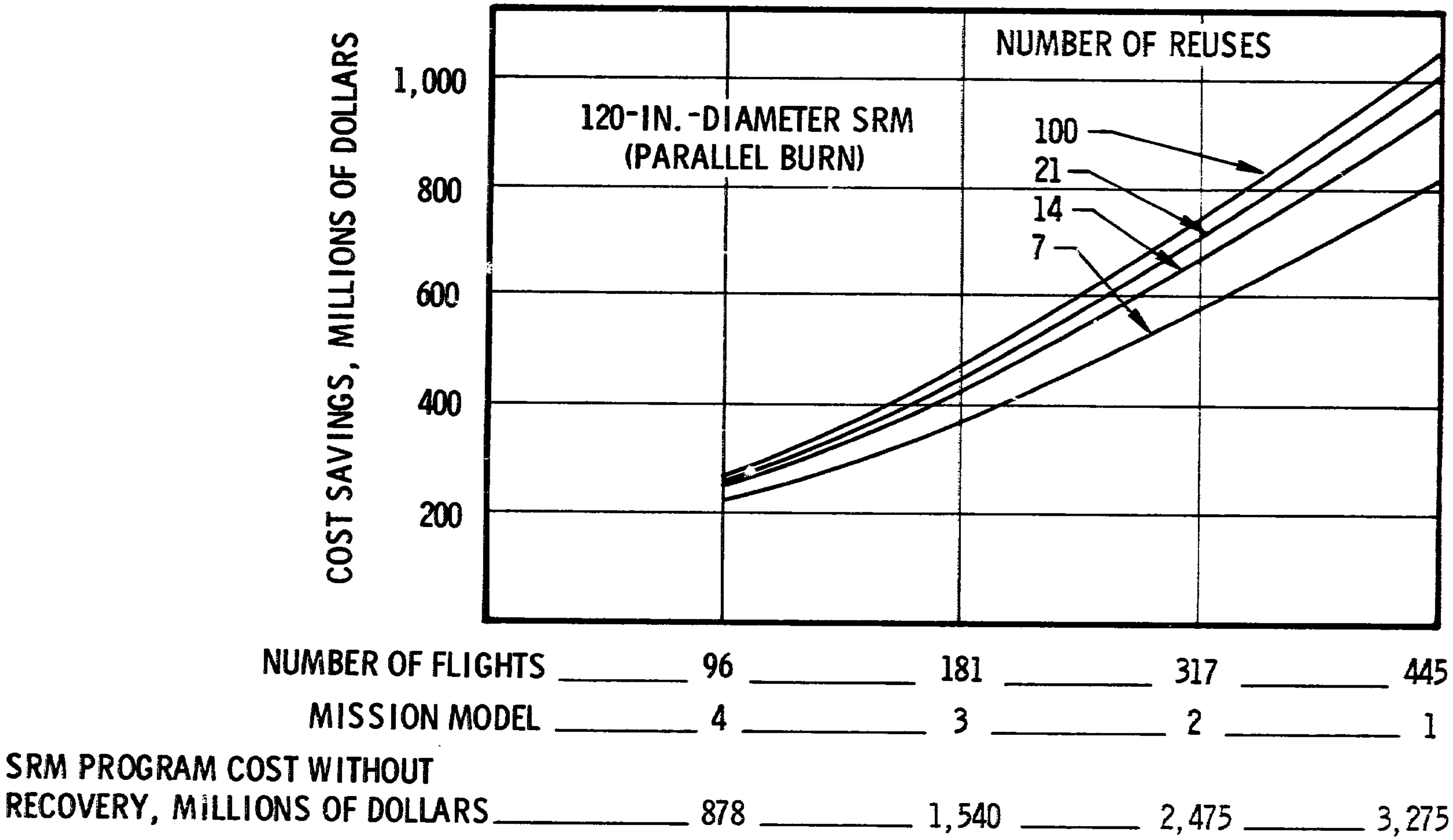


Figure 2-9. Program Savings Based on Recovery and Reuse

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